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THE INFLUENCE OF PLANTING DATE OF CARROT ON *MELOIDOGYNE INCOGNITA* REPRODUCTION AND INJURY TO ROOTS

BY

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Carrot cv. Emperator was direct seeded into *Meloidogyne incognita* infested sandy loam field plots at Tustin, southern California, on five dates each two weeks apart starting in mid-October. Harvest dates were similarly staggered in the following spring. Significant differences in plant weights at harvest were not found. Percentages of tap roots rendered unmarketable due to galling and forking symptoms were 50.3, 30.8, 19.3, 8.9 and 11.2 respectively on the five plantings. Root injury was related to the level of infection in early season, as influenced by soil temperatures that fluctuated near the *M. incognita* activity threshold of 18°C. Accumulated temperature, particularly from mid-season onward, determined final nematode numbers, which were significantly ($P = 0.05$) more on the fourth and fifth plantings. The importance of changing planting dates of winter vegetables for suppressing root-knot nematodes was demonstrated.

Keywords: Root-knot nematodes, *Daucus carota sativa*, accumulated temperature, cultural control, nematode development.

Time of planting studies in southern California revealed that the root-knot nematode, *M. incognita* (Kofoid & White) Chitwood, was not able to penetrate roots of susceptible winter wheat (*Triticum aestivum* L. em Thell) plants in the field at soil temperatures below 18°C (Roberts *et al.*, 1981). Controlled temperature studies on migration of *M. incognita* through soil columns towards susceptible tomato (*Lycopersicon esculentum* (L.) Mill.) roots also demonstrated a significant lessening in nematode mobility and root penetration below 18°C (Prot & Van Gundy, 1981). This minimum 'activity threshold' of 18°C for *M. incognita* second-stage juveniles (J2) (Roberts *et al.*, 1981) is considerably higher than the 10°C minimum temperature required for *M. incognita* to develop in roots (Vrain *et al.*, 1978).

Wheat was tolerant to injury by invading *M. incognita* when planted in soil above 18°C (Roberts & Van Gundy, 1981; Roberts *et al.*, 1981). However, the infected plant supported the completion of one generation of *M. incognita* during winter, resulting in increased spring final population levels in soil (Roberts *et al.*, 1981). In India, delay in autumn planting at similar temperatures reduced *M. incognita* injury to chickpea (Gaur *et al.*, 1979).

Carrot (*Daucus carota sativa* L.) is sensitive to 'cosmetic injury' resulting from galling and forking of the tap root (see Lamberti, 1971) by initial numbers of nematodes that do not cause measurable reduction in carrot plant growth (Vrain, 1982). Therefore the potential was investigated of using time of planting in relation to the *M. incognita* activity threshold to minimize nematode injury to carrot as well as to manipulate nematode population density after harvest. A preliminary report on part of this study was made previously (Roberts, 1983).

MATERIALS AND METHODS

Plots were established in autumn 1980 on a sandy loam field near Tustin, California. The site was infested with *M. incognita* that had been increased on squash (*Cucurbita pepo* L.) from June to September. Five planting date treatments were completely randomized within each of three replicate blocks. Individual plots consisted of three beds; beds were 1.02 m apart and 8.0 m long, with two plant rows (0.25 m apart) per bed. Carrot cv. Emperator was direct seeded into pre-irrigated beds and sprinkle irrigated as needed. Standard fertilizer and weed management practices were applied during the season. Planting and harvest dates of each treatment are given in Table I.

At harvest, carrots were mechanically lifted and a 200-carrot whole plant sample was collected from the four center rows of each plot and weighed. Then the tops were weighed separately and tap roots were graded into three categories irrespective of size—marketable non-damaged; unmarketable-forking symptoms; unmarketable-galling symptoms.

Numbers of nematodes in soil were determined at time of first planting in all treatments and immediately after harvest in each treatment. Two soil samples per plot were collected at time of first planting and also immediately after harvest. Each sample consisted of 10 cores (2 × 35 cm deep), 475 cm^3 of soil of which was processed through a 40-mesh sieve to collect egg-masses and through a 325-mesh sieve followed by Baermann funnel extraction to collect second-stage juveniles.

TABLE I

Planting and harvest dates and accumulated DD_{10} during the season for five carrot plantings

Planting	Planting date	Harvest date	DD_{10}* days
1	10/16/80	04/06/81	1,018
2	10/27/80	04/16/81	1,020
3	11/06/80	04/30/81	1,099
4	11/18/80	05/14/81	1,161
5	12/01/80	05/26/81	1,311

* DD_{10} accumulated from first day after emergence ≥18°C until harvest, using soil temperatures.

At weekly or biweekly intervals from emergence, samples of fifty root systems 25 cm deep were removed from each treatment, washed in tap water, damp-dried and fixed in 5% formalin. Whole roots of young plants, or feeder roots of older plants removed from the tap root together with the terminal portion of the tap root (distal to root diameter of 1 cm), were washed in tap water to remove fixative, damp-dried and weighed, stained in acid fuchsin lactophenol, washed under running water and examined in glycerol for *M. incognita* juvenile and adult stages. The weights of root samples collected and examined in the early season infection study are given in Table II. From later root samplings a 5-gram subsample of roots was examined for nematodes.

Soil temperature in the carrot rhizosphere at 15 cm depth was recorded continuously with a soil temperature recorder (Foxboro Co., Foxboro, Mass.). Accumulated temperature (degree days, DD_{10}) above a basal thermal threshold for *Meloidogyne* development of 10°C (50°F), was calculated with a computer program that integrates the area under sine curves fitted through the daily maximum and minimum temperature values.

TABLE II

Early season root infection by Meloidogyne incognita *in five carrot plantings*

Weeks from carrot	Nematodes/gram root*				
emergence	P1	P2	P3	P4	P5
1	-	-	0 (0.4)	0 (0.3)	-
2	27 (0.8)†	26 (0.8)	13 (0.6)	1 (0.5)	0 (0.4)
3	34 (1.7)	95 (1.3)	86 (0.7)	2 (0.7)	0 (0.6)
4	34 (2.8)	23 (2.7)	14 (1.8)	2 (1.4)	0 (1.2)
5	37 (4.8)	44 (4.5)	16 (3.6)	5 (2.9)	2 (2.0)
6	304 (7.8)	123 (6.7)	15 (5.8)	4 (5.1)	4 (4.7)

* Values from a composite sample of 50 root systems.
† Values in parentheses are root weights (grams) of composite samples.

RESULTS

The high mean weekly and average mean weekly soil temperatures recorded during the experiment are presented in Fig. 1. The numbers of days per week with temperature >18°C are given for those weeks where the high mean weekly temperature was <18°C. All plantings were exposed to at least some days with soil temperature >18°C soon after emergence, but the fourth and fifth plantings emerged when soil temperature <18°C on most days. Soil temperature remained above 10°C throughout the experiment. The total DD_{10} accumulated from the first day after carrot emergence when soil temperature ≥18°C until harvest are given in Table I.

The first planting had a significantly ($P = 0.05$) higher percentage of forked and galled roots than subsequent plantings, and the second planting had a

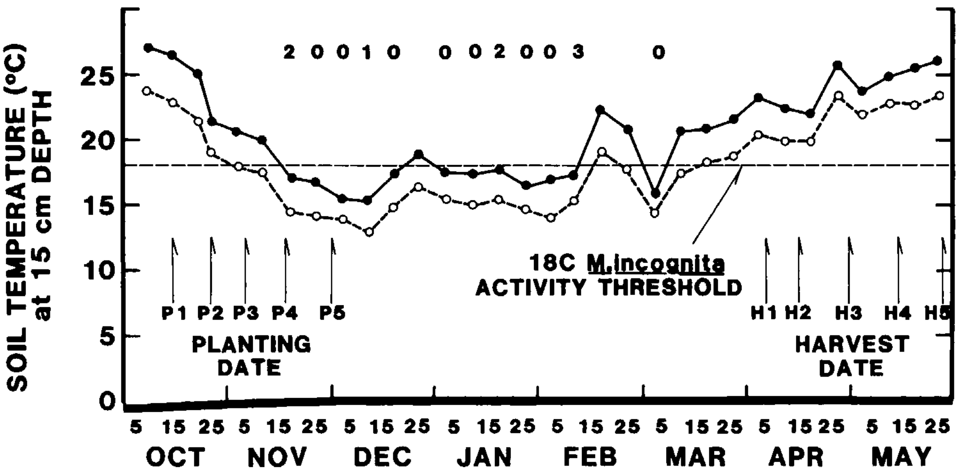

Fig. 1. High and average mean weekly soil temperature at 15-cm depth during winter growing season in Tustin, southern California. Time of planting (P1-5) and harvest (H1-5) are indicated.

significantly higher (P = 0.05) percentage of forked and galled roots than later plantings, and the second planting had a significantly higher (P = 0.05) percentage of roots damaged in this way than the fourth and fifth plantings. Conversely, later plantings had a correspondingly higher percentage of marketable tap roots than earlier plantings (Fig. 2). Planting treatments did not differ significantly in total fresh weight of tap roots or in total fresh weight of plant tops.

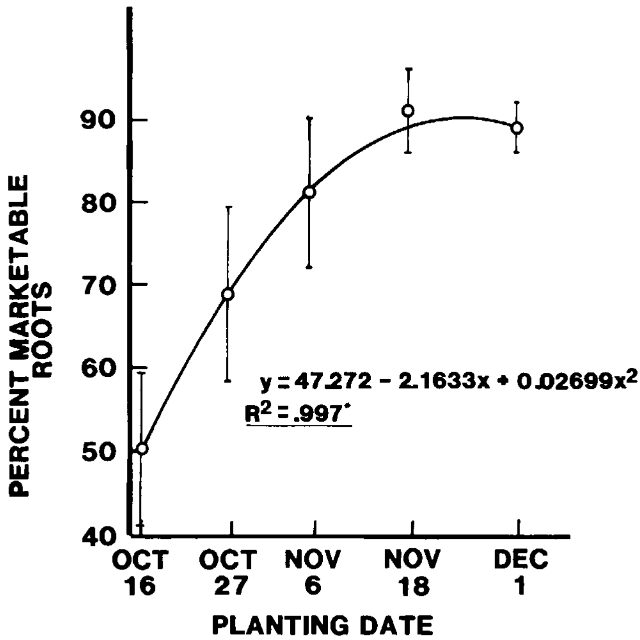

Fig. 2. Percentages (± Std. Devn.) of marketable tap roots in five plantings.

The numbers of *M. incognita* (all stages) in roots during six weeks after carrot emergence were progressively fewer the later the planting (Table II) and there was less galling and forking of young roots in later plantings, even when similar numbers of nematodes were found inside roots. For example, the second planting was less heavily forked and galled than the first planting and more heavily forked and galled than the third planting during weeks 2 to 5 from emergence.

Initial numbers of *M. incognita* were not significantly different between treatments, ranging from 2,275 to 3,390 eggs and J2/475 cm^3 soil. J2 final population levels in the first and fifth plantings were similar, and significantly ($P = 0.05$) higher than in the third planting, whereas levels in the second, third and fourth plantings were not significantly different (Fig. 3). Egg numbers were significantly greater in the first planting than in the second and third plantings; however all three were significantly ($P = 0.05$) less than the much larger numbers of eggs produced in the fourth and fifth plantings (Fig. 3).

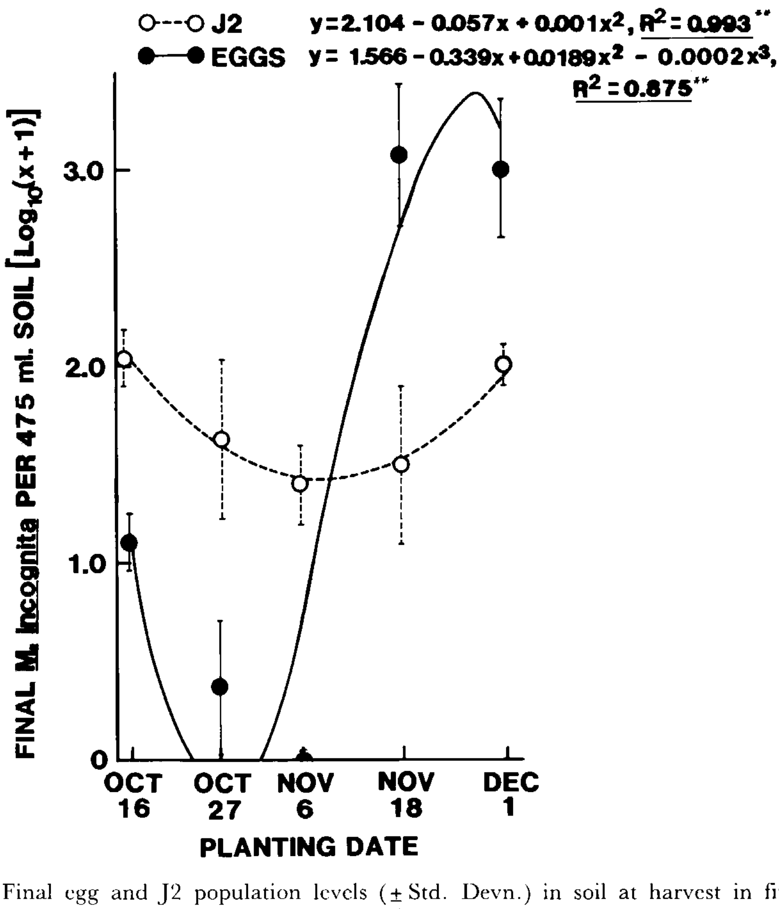

Fig. 3. Final egg and J2 population levels (± Std. Devn.) in soil at harvest in five carrot plantings.

DISCUSSION

The percentage of tap roots damaged in the second planting was 20 percent less than in the first planting, even though both plantings had similar accumulated DD_{10} totals for the season. Later plantings had even less tap root damage although more DD_{10} were accumulated by later plantings (Table I). The DD_{10} accumulations were made from the first day following emergence when soil temperature was favorable ($\geq 18°C$) for J2s to penetrate into roots. Therefore, soil temperature and nematode activity during early root development appear more important for tap root disfiguration, rather than accumulated temperature and nematode development during the season.

In the fourth and fifth plantings, the few days in early season following emergence when soil temperature $\geq 18°C$ restricted the penetration of J2s into roots. These results accord with previous studies that used tomato and wheat to demonstrate restriction of *M. incognita* migration and root penetration activity below 18°C soil temperature (Prot & Van Gundy, 1981; Roberts *et al.*, 1981).

Soil temperatures were above the 10°C minimum temperature threshold for development throughout the experiment. Therefore any juvenile inside a root had enough heat units to develop in each planting. The delay in harvest, required for later plantings to mature, provided *M. incognita* with more DD_{10} in late winter and early spring and greater total DD_{10}. Estimates of heat units required for egg laying per female by *M. arenaria* and *Meloidogyne* sp. from California are about 0.5 to 1.0 eggs/DD_{10} (Ferris *et al.*, 1984; Tyler, 1933).

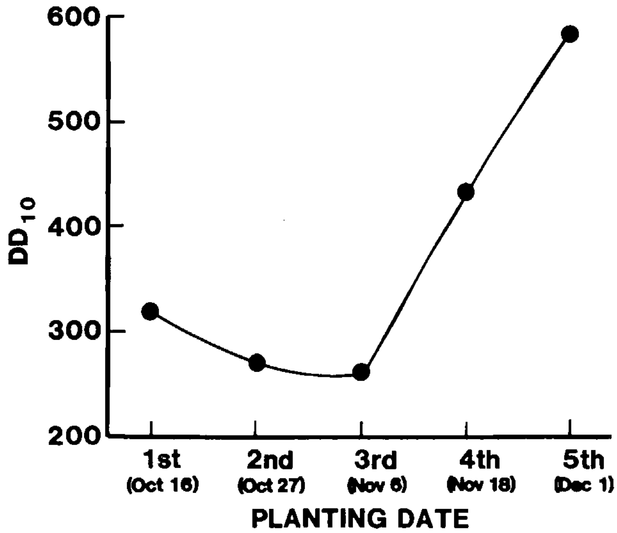

Fig. 4. Accumulated temperature (DD_{10}), from time when about half the nematodes in roots were egg-laying females until harvest.

The accumulated DD_{10} from the time that about half the individuals in the roots had developed into egg-laying females until harvest for the different plantings ranged from 260-585 DD_{10} (Fig. 4). This relationship conforms closely to that of the final numbers of *M. incognita* in soil for the different plantings, particularly final numbers of eggs (Fig. 3). Greater egg production and larger final numbers in the soil occurred in the late plantings, even though early season root infection was less than in the early plantings.

The previous studies on wheat at the same site demonstrated the benefit of preventing *M. incognita* reproduction in winter by delaying planting in autumn until soil temperature declined below 18°C. In the spring, temperature did not reach 18°C before wheat roots were already senescing prior to harvest (Roberts *et al.*, 1981). In the current study, the earlier than normal spring temperature rise (above 18°C in mid-February) and the presence of active host roots well into spring enabled *M. incognita* to reproduce on the delayed plantings. Thus the benefit derived from reduction in tap root damage by delayed planting was offset by increasing the primary inoculum for the next susceptible crop. However, the benefit of lessening root-knot nematode damage to carrot and to other winter grown crops by delayed planting should be considered as an important control tactic, especially where other control procedures are either not available or are not economical. Implementation of this procedure for specific crops requires local study within a given climatic region, using local historical temperature records (see Jones, 1975).

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ZUSAMMENFASSUNG

Der Einfluß des Aussaattermins von Möhren auf die Vermehrung von Meloidogyne incognita *und auf die Wurzelschäden*

Möhren der Sorte Emperator wurden direkt auf einem mit *Meloidogyne incognita* befallenem Feld mit sandigem Lehm bei Tustin, Südkalifornien ausgesät. Die Aussaat erfolgte ab Mitte Oktober an fünf jeweils zwei Wochen auseinanderliegenden Terminen. Entsprechend gestaffelt wurde dann im nächsten Frühjahr geerntet. Bei der Ernte konnten keine signifikanten Unterschiede im Pflanzengewicht festgestellt werden. Der Anteil der wegen Gallenbildung und Beinigkeit nicht marktfähigen Ware betrug bei den fünf Ernteterminen 50,3; 30,8; 19,3; 8,9 und 11,2%.

Das Ausmaß der Wurzelschäden hing ab von der Infektionsstärke zu Beginn der Wachstumsperiode, die ihrerseits von den um 18°C, der Aktivitätsgrenze von *M. incognita*, schwankenden Bodentemperaturen beeinflußt wurde. Die Wärmesumme bestimmte vor Allem von der Mitte der Wachstumsperiode an die Endpopulation, die beim vierten und fünften Aussaattermin signifikant ($p = 0{,}05$) höher war. Mit den Versuchen wurde die Bedeutung der Wahl des Aussaattermins als Kulturmaßnahme zur Unterdrückung von Wurzelgallennematoden an Wintergemüse gezeigt.

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